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ORIGINAL ARTICLE

Evaluation of two compact electronic apex locators in the presence of different endodontic solutions

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Working length

Abstract The purpose of this study was to evaluate the accuracy of two compact electronic apex locators, the Root ZX mini and the Mini Apex Locator, in the presence of different endodontic solutions and to compare their performance to the Root ZX electronic apex locator. The sample consisted of 60 extracted single-rooted human teeth. Manufacturers' recommendations were followed to operate each electronic apex locator to determine electronic length in the presence of 5.25% Sodium Hypochlorite, 2.625% Sodium Hypochlorite, 1.0% Sodium Hypochlorite, 0.9% NaCl, 2% lidocaine with 1:80,000 Epinephrine, and 2% Chlorhexidine. The difference between the electronic (EL) and actual length (AL) was calculated. In addition, EL measurements were classified into three categories: "correct" (AL ± 0.5 mm), "long" (>0.5 mm from AL), "short" (<−0.5 mm from AL). There were no statistically significant differences in the accuracy of each of the three apex locators in the presence of the six endodontic solutions used in this study. The Root ZX mini and the Mini Apex Locator had similar accuracy to the Root ZX in the presence of each endodontic solution. It is concluded that the Root ZX mini and Mini Apex Locator have similar accuracy to the Root ZX and that the function of the three apex locators was not affected by the type of endodontic solution used.

1. Introduction

Treatment outcome of root canal therapy is dependent on correct determination of the working length (AAoE, 2011) to ensure removal of the contents of the root canal system followed by filling the root canal system without under- or over-filling (Seltzer et al., 1963; Sjogren et al., 1990). According to the American Association of Endodontists Glossary of Endodontic Terms, root canal working length is defined as "the distance from a coronal reference point to the point at which canal preparation and obturation should terminate" (AAoE, 2011). The point at which the root canal preparation should terminate apically is the cementodentinal junction which

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is generally considered to be at the level of the apical constriction or minor foramen (Gordon and Chandler, 2004). The apical constriction is the narrowest area in the root canal system. Severing the pulp tissues at this point will produce the smallest possible wound, thereby promoting better tissue healing (Ricucci and Langeland, 1998). Although the apical constriction is a well-defined anatomic landmark, establishing working length to this point could be very demanding. Working length determination methods include anatomical averages of tooth length, tactile sensation, patient response, paper points, radiographs, and electronic apex locators (Gordon and Chandler, 2004).

Currently, the use of electronic apex locators to determine working length during root canal therapy is widely accepted in the endodontic profession. This acceptance of the electronic apex locators started with the introduction, in the early 1990s, of the Root ZX apex locator (J. Morita Corp., Tokyo, Japan). The Root ZX popularity is attributed to its ease of use combined with evidence-based accuracy in determining working length (Shabahang et al., 1996; Vajrabhaya and Tepmongkol, 1997; Welk et al., 2003; Gordon and Chandler, 2004). Following the success of the Root ZX, manufactures started to introduce other models of electronic apex locators. Although modern electronic apex locators are generally considered to be accurate in determining the root canal working length, some variations in their performance have been reported in the literature (De Moor et al., 1999; Welk et al., 2003; Hoer and Attin, 2004; Plotino et al., 2006; Bernardes et al., 2007; Pascon et al., 2009). The reported differences in the accuracy of electronic apex locators make it necessary to continuously evaluate the accuracy of newly introduced electronic apex locators.

The practice of modern endodontics involves the use of several devices that aid the clinician diagnose, prepare, and fill the root canals. This increase in the list of endodontic office equipment has led to the introduction of space saving solutions that include combining multiple endodontic devices in one machine and reducing the size of certain devices. The Mini Apex Locator (SybronEndo, Redmond, WA, USA) and the Root ZX mini (J. Morita Corp., Tokyo, Japan) are two compact apex locators that have been recently introduced to the market. The Mini Apex Locator uses a sophisticated, multi-frequency, and all digital measurement system (Bernardes et al., 2007; D'Assuncao et al., 2007); while the Root ZX mini is based on the electronics of the Root ZX (Stoll et al., 2010). Some initial published papers on the performance of the Mini Apex Locator have suggested high accuracy (D'Assuncao et al., 2007; de Camargo et al., 2009) while others have reported lower accuracy (Siu et al., 2009; D'Assuncao et al., 2010). On the other hand, the Root ZX mini is reported to have similar accuracy to the Dentaport ZX (Stoll et al., 2010).

Modern electronic apex locators are believed to be able to perform well in the presence of various irrigation solutions (Weiger et al., 1999; Kaufman et al., 2002; Tinaz et al., 2002; Kang and Kim, 2008); however, some reports suggest that accuracy of electronic apex locators is dependent on the type of irrigation solution used (Jenkins et al., 2001; Erdemir et al., 2007; Ozsezer et al., 2007). In addition, reports on the use of 2% Chlorhexidine as irrigation solution are showing promising results (Leonardo et al., 1999; Ercan et al., 2004), yet no report on the effect of this irrigation solution on the performance of electronic apex locators is available in the literature. Therefore, the aim of this study was to evaluate the accuracy of two compact electronic apex locators, the Root ZX mini and the Mini Apex Locator, in the presence of different irrigation solutions and to compare their performance to the Root ZX electronic apex locator.

2. Materials and methods

Sixty extracted single-rooted human teeth were used in this study. Calculus and gross organic residues were removed with a scaler. The teeth were stored in 10% formalin until needed. The teeth were rinsed with tap water, and complete root apex formation and absence of root fracture were verified by examination under a Swift stereo eighty stereomicroscope (Swift Instruments International S.A., Tokyo, Japan) at 20×. Access cavity preparations were made following standard procedures using carbide burs; the content of the root canal system was then removed. To create a stable and reproducible reference point, the incisal and occlusal edges were planed with a straight fissure bur. The teeth were pre-flared using size #2–4 Gates-Glidden drills to improve the performance of the electronic apex locators (Ibarrola et al., 1999; de Camargo et al., 2009). A single operator determined root canal lengths under 20× magnification of the stereomicroscope by inserting a size number 10 K-FlexoFile (Dentsply-Maillefer, Baillagues, Switzerland) with a silicone stop into the root canal. The file was advanced apically until the tip was at the plane of the major foramen. The silicone stop was adjusted to fit the reference point, the file was withdrawn, and the distance between the file tip and the silicon stop was measured to the nearest 0.5 mm with an endodontic ruler. Then 0.5 mm was subtracted from this measurement (Plotino et al., 2006). Each measurement was repeated two times and the average reading was recorded as the actual length (AL).

The sample was randomly divided into six subgroups, each containing 10 teeth. Each group of teeth was mounted into a silicone mold (Additional curing silicone for duplication, YETI Dentalprodukte GmbH, Engen, Germany) using alginate (Jeltrate dustless, Dentsply-Caulk, Milford, DE, USA) that was prepared according to the manufacturers' instructions to the level of the cementoenamel junction (Kaufman et al., 2002; Baldi et al., 2007). Before the alginate sets, the electronic apex locator metal lip clip was inserted into the mold. All measurements were made within one week of model preparation. When not in use, the alginate models were stored in a humid chamber at room temperature.

The following irrigation solutions were used in this study: 5.25% Sodium Hypochlorite (5.25% NaOCl), 2.625% Sodium Hypochlorite (2.625% NaOCl), 1.0% Sodium Hypochlorite (1.0% NaOCl), 0.9% NaCl (0.9% normal saline), 2% lidocaine with 1:80,000 Epinephrine (local anesthetic) (Dentsply Pharmaceutical, PA, USA), 2% Chlorhexidine (Essential Dental Systems INC., NJ, USA). During the experiment, the root canals were irrigated with the irrigation solution of interest using an endodontic syringe; the pulp chamber was dried with cotton pellets leaving the canal filled with the irrigating solution. Following the use of each irrigation solution in the electronic apex locator measurement, the root canal was dried with paper points, rinsed with 10 ml of 0.9% normal saline, dried again with paper points, and then the next irrigation solution was introduced into the root canal. All the teeth were tested by the three electronic apex locators in the presence of the six types of irrigation solutions. To minimize bias that might be introduced by

the sequence of using the apex locators or irrigation solution, each of the six teeth groups was tested first by a different irrigation solution in a predetermined systematic manner. In addition, the use of electronic apex locators was performed in a systematic manner to ensure that each apex locator was used first on one-third of the teeth sample, used second on one-third of teeth sample, and as the last apex locator on one-third of the teeth sample.

The operation of each electronic apex locator was according to the manufacturers' instructions on the user manual, and the apical constriction as indicated by each device was used as the apical reference. The electronic working length (EL) was determined by attaching a size number 15 K-FlexoFile to the electronic apex locator electrode and advancing it into the canal until each apex locator indicated that the desired working length reference point has been reached. For the Root ZX mini apex locator, the file was introduced into the canal until the "apex" on the unit's display was flashing with an accompanying solid audible sound, the file was then retracted to the level of the flashing bar between the "apex" and the"1.0" mark at the level of the small triangle on the right side of the display and a "00" reading was visible on the numeric display to the left. The file was then removed and the distance between the file tip and the silicon stop was measured and recorded as the EL. For the Mini Apex Locator, the file was advanced into the canal until orange LED light at the "Past Apex" mark is turned on, the file was then withdrawn until the green LED light at the "Apex" mark is turned on combined with the distinctive audible signal. The file was then removed and the distance between the file tip and the silicon stop was measured and recorded as the EL. For the Root ZX, the file was introduced into the canal until the "apex" on the unit's display was flashing combined with a solid audible sound, the file was then retracted to the level of the flashing bar between the "apex" and the"1.0" mark with a flashing tooth on the side. The file was then removed and the distance between the file tip and the silicon stop was measured and recorded as the EL. All readings were considered correct when the distinctive features for each device indicating that the desired working length reference point has been reached were stable for at least 5 s. A single operator performed all the measurements. Each measurement was performed twice and the average was recorded.

The recorded EL was compared with AL by subtracting the AL from EL. A positive value indicates that the EL exceeds AL (long) and a negative value indicates that EL measurement is short of the AL. In addition, EL measurements were classified into three categories based on the EL file tip position relative to the AL reference point: "correct" (AL ± 0.5 mm), "long" (>0.5 mm from AL), and "short" (<−0.5 mm from AL). The data were analyzed using ANOVA followed by Schafee post hoc ($p < 0.05$) for difference in means; and using Chi-square for differences between categories of EL file tip position relative to the AL reference point.

3. Results

The results for the mean difference between EL and AL as well as the number and percentage of readings in each of the categories that are based on the EL file tip position relative to the AL reference point in the presence of the six irrigation solutions are presented in Table 1 for the Root ZX mini, Table 2 for the Mini Apex Locator, and Table 3 for the Root ZX. There were no statistically significant differences for the mean difference between EL and AL in the presence of different irrigation solutions for the Root ZX mini ($p = 0.75$), the Mini Apex Locator ($p = 0.92$), or the Root ZX ($p = 0.44$). Similarly, there were no statistically significant differences between the "correct" (AL ± 0.5 mm), "long" (>0.5 mm from AL), and "short" (<−0.5 mm from AL) categories in the presence of different irrigation solutions for the Root ZX mini ($p = 0.56$), the Mini Apex Locator ($p = 0.63$), or the Root ZX ($p = 0.64$). For each irrigation solution, there were no statistically significant difference between the "correct" (AL ± 0.5 mm), "long" (>0.5 mm from AL), and "short" (<−0.5 mm from AL) categories for the measurements performed by the Root ZX mini, the Mini Apex Locator, or the Root ZX ($p = 0.08$).

4. Discussion

The results of this study indicate that the two compact electronic apex locators, the Root ZX mini and the Mini Apex Locator, have similar accuracy in determining the root canal working length to the Root ZX electronic apex locator. In addition, the accuracy of the three apex locators was not affected by the type of irrigation solution present in the root canal. Our findings are in agreement with previous studies that found the Mini Apex Locator to have similar accuracy to the Root ZX (de Camargo et al., 2009) and the root ZX II.(D'Assuncao et al., 2007) On the other hand, D'Assuncao et al. (2010) reported the Mini Apex Locator to be less accu-

Table 1 Mean, standard deviation (SD), minimum (Min.), maximum (Max.), and distribution of readings (in mm) for the difference between actual length (AL) and readings of the Root ZX mini (EL).

Irrigation solution	*n*	Mean	SD	Min.	Max.	Distribution of electronic readings relative to the actual length					
						<−0.5 "short"		−0.5 to +0.5 "correct"		>0.5 "long"	
						n	%	*n*	%	*n*	%
2.25% NaOCl	60	0.48	0.38	−0.5	1.25	0	0	42	70	18	30
2.625% NaOCl	60	0.49	0.29	0.0	1.25	0	0	45	75	15	25
1.0% NaOCl	60	0.48	0.30	0.0	1.25	0	0	47	78	13	22
0.9% Normal saline	60	0.43	0.35	−0.5	1.25	0	0	48	80	12	20
Local anesthetic	60	0.51	0.32	0.0	1.50	0	0	45	75	15	25
2% Chlorhexidine	60	0.51	0.31	0.0	1.25	0	0	40	67	20	33

Negative value indicates that the file position is coronal to the actual length.

Table 2 Mean, standard deviation (SD), minimum (Min.), maximum (Max.), and distribution of readings (in mm) for the difference between actual length (AL) and readings of the Mini Apex Locator (EL).

Irrigation solution	*n*	Mean	SD	Min.	Max.	Distribution of electronic readings relative to the actual length					
						< −0.5 "short"		−0.5 to +0.5 "correct"		> 0.5 "long"	
						n	%	*n*	%	*n*	%
2.25% NaOCl	60	0.28	0.42	−0.75	1.0	1	2	49	82	10	16
2.625% NaOCl	60	0.33	0.39	−0.5	1.25	0	0	47	78	13	22
1.0% NaOCl	60	0.31	0.39	−0.75	1.0	1	2	48	80	11	18
0.9% Normal saline	60	0.30	0.36	−1.0	1.25	1	2	53	88	6	10
Local anesthetic	60	0.35	0.32	−0.25	1.25	0	0	54	90	6	10
2% Chlorhexidine	60	0.34	0.33	−0.25	1.25	0	0	50	83	10	17

Negative value indicates that the file position is coronal to the actual length.

Table 3 Mean, standard deviation (SD), minimum (Min.), maximum (Max.), and distribution of readings (in mm) for the difference between actual length (AL) and readings of the Root ZX Apex Locator (EL).

Irrigation solution	*n*	Mean	SD	Min.	Max.	Distribution of electronic readings relative to the actual length					
						< −0.5 "short"		−0.5 to +0.5 "correct"		> 0.5 "long"	
						n	%	*n*	%	*n*	%
2.25% NaOCl	60	0.46	0.34	−0.5	1.25	0	0	47	78	13	22
2.625% NaOCl	60	0.43	0.31	0.0	1.25	0	0	50	83	10	17
1.0% NaOCl	60	0.44	0.32	−0.25	1.25	0	0	48	80	12	20
0.9% Normal saline	60	0.46	0.31	0.0	1.25	0	0	47	78	13	22
Local anesthetic	60	0.52	0.28	0.0	1.50	0	0	46	77	14	23
2% Chlorhexidine	60	0.53	0.34	0.0	1.25	0	0	42	70	18	30

Negative value indicates that the file position is coronal to the actual length.

rate than the Root ZX II in determining the precise location of the apical constriction; however, both apex locators had 100% correct readings if ± 0.5 mm tolerance limit from the apical constriction was allowed. In addition, Siu et al. (2009) reported low accuracy of the Mini Apex Locator in locating the minor diameter (within ±0.5 mm), this is probably attributed to the experimental conditions especially the use of a nickel–titanium rotary device to determine working length since the Root ZX II had a similar low accuracy (50%) to the Mini Apex Locator (40%). The accuracy of the Root ZX mini reported in our study (≈75%) is lower than the 94% accuracy reported by Stoll et al. (2010); however, in the latter study, the Root ZX mini accuracy was similar to the Dentaport ZX (a Root ZX II with an attached rotary motor module). This is similar to our findings of comparable accuracy of the Root ZX mini to the Root ZX.

The type of irrigation present in the canal did not affect the function and accuracy of the three apex locators tested in this experiment. This finding is in agreement with previously published reports that tested other apex locators in the presence of various irrigation solutions (Weiger et al., 1999; Kaufman et al., 2002; Tinaz et al., 2002; Kang and Kim, 2008). The use of 0.9% normal saline as an irrigation solution has been reported to lower the accuracy of some electronic apex locators (Erdemir et al., 2007; Ozsezer et al., 2007), while other reports indicate that it had no effect on the accuracy of electronic apex locators (Weiger et al., 1999; Kaufman et al., 2002; Kang and Kim, 2008). The present study found no adverse effect of using 0.9% normal saline as an irrigation solution on the accuracy of the three apex locators tested.

The use of 2% Chlorhexidine as an irrigation solution has been advocated to take advantage of its good antimicrobial properties and its residual effect in the root canal (Leonardo et al., 1999; Ercan et al., 2004). The effect of lower Chlorhexidine concentrations (0.1%, 0.2%, and 0.8%) on the accuracy of electronic apex locators has been previously investigated (Kaufman et al., 2002; Ebrahim et al., 2007; Kang and Kim, 2008); however, this is the first study to report on the effects of 2% Chlorhexidine on the accuracy of electronic apex locators. Our findings indicate that the presence of 2% Chlorhexidine in the root canal will not affect the accuracy of the three electronic apex locators used in this study.

Studies evaluating the accuracy of electronic apex locators use a wide range of experimental procedures to conduct the study, and to record and report findings. These experiments could be either *in vivo* or *ex vivo* (Shabahang et al., 1996; Pascon et al., 2009). A number of *ex vivo* models have been used that include 1% agar, gelatin, alginate, 0.9% saline, and flower sponge soaked in 0.9% saline (Baldi et al., 2007). The actual working length can be determined by visually observing, at the apical foramen, the tip a file inserted into the canal (Lucena-Martin et al., 2004; Pascon et al., 2009); or to determine the location of the tip of the file that was used for the electronic working length measurement relative to the apical constriction by cementing it in the canal and then exposing the apical 4 mm of the root canal (Welk et al., 2003; Hoer and Attin, 2004). In addition, the apical reference point for recording the electronic length can be set at the "apex" indicator on the device electronic dial (Lucena-Martin et al., 2004; Guise et al., 2009), the "0.5 mm" mark (Plotino et al., 2006; Pascon et al., 2009), or

the "−1.0 mm" mark (Bernardes et al., 2007; de Camargo et al., 2009). Furthermore, the findings have been reported as percentage of readings that are exactly at or fall within a certain tolerance level that ranges from ±0.5 mm to ±1.0 mm with regard to a predetermined reference point that could be the apical foramen (Lucena-Martin et al., 2004), the actual apical constriction (Tselnik et al., 2005), estimated apical constriction (apical foramen – 0.5 mm) (Plotino et al., 2006), or 1 mm short of the apical foramen(Pascon et al., 2009).

In the present study, an *ex vivo* alginate model was used to mount the teeth in preparation for testing. Alginate has been previously reported to be an acceptable and stable set-up to test electronic apex locators for up to 45 days (Kaufman et al., 2002; Baldi et al., 2007). In addition, the sequence of testing irrigation solutions and electronic apex locators was systematically varied to minimize any bias that might be introduced due to dimensional change of the alginate. Actual working length was determined to be 0.5 mm short of the apical foramen to estimate the location of the apical constriction. This method was chosen because the apical foramen is a reproducible point that is easy to locate. In addition, this method has been previously reported in the literature (Plotino et al., 2006; D'Assuncao et al., 2007). Furthermore, locating the apical constriction visually after exposing the apical part of the root canal can be challenging since less than 50% of the teeth have a definitive constriction point (Lee et al., 2002). The results of this study were reported as percentage of readings within a predetermined range; where the zone between the apical foramen and 1.0 mm coronal to that (estimated apical constriction ±0.5 mm) was considered "correct", readings beyond the apical foramen were considered "long", and readings more than 0.5 mm short of the estimated apical constriction were considered "short". This was adopted with modification from Hoer and Attin (2004) who considered the area between the apical foramen and the apical constriction to be the "target" interval. The use of the zone between the apical foramen and 1.0 mm coronal to it (estimated apical constriction ±0.5 mm) as a "target" or "correct" zone provides several advantages including easy and reproducible determination of the reference length (actual length), root canal preparation and obturation will be within the limits of the root canal system, and electronic readings that are considered "correct" are within the clinical tolerance limits.

The accuracy of the two compact electronic apex locators, the Root ZX mini and the Mini Apex Locator has been shown in this study to be similar to the accuracy of the Root ZX. The performance of the three apex locators was not affected by the presence of the six irrigation solutions used in this study. Based on available scientific evidence, it seems reasonable to assume that modern apex locators will work well in the presence of different irrigation solutions thereby providing endodontists with greater flexibility in their choice of irrigation solution. However, continuous testing of new electronic apex locators in the presence of traditional and new irrigation solutions is required to ensure quality and consistency of performance.

5. Conclusions

In the present study, the two compact electronic apex locators, the Root ZX mini and the Mini Apex Locator, were found to have similar accuracy in determining the root canal working length to the Root ZX. The use of 5.25% NaOCl, 2.625% NaOCl, 1.0% NaOCl, 0.9% normal saline, 2% lidocaine with 1:80,000 Epinephrine, or 2% Chlorhexidine as irrigation solutions did not affect the accuracy of the three apex locators in determining working length.

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